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Research Note

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A PUMP-MANOMETER FOR GROUND WATER STUDIES

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ABSTRACT

The pump-manometer provides a way to quickly and accurately measure hydraulic conductivity in the field by means of either the auger-hole method or the piezometer method. The device can be operated easily by a two-man crew, but with practice one man could perform the entire operation. The particular advantage of the manometer is that measurement of the rate of rise of water can begin as soon as the well is pumped dry without removing one instrument from the well and inserting another.

Hydrologists and engineers are often concerned with measuring the hydraulic conductivity of the soil. Many methods have been developed for the field measurement of hydraulic conductivity in saturated soils (Luthin 1957). Two of the most popular techniques are the auger-hole method and the piezometer method.

The mathematical expression of hydraulic conductivity for each of these techniques includes the rate of rise of water in a well pumped dry and also a term to indicate the depth of the water in the well below the static water level (Boersma 1965).

The accuracy of each of these methods depends largely upon careful measurements of the rate of rise of the water and the depth to the water level at any instant. One of the difficulties in using these techniques is the lag in time that occurs between pumping a well dry and starting to measure the rise of water in the well. This paper describes a combination pump and manometer which will allow the operator to pump a well dry, then, without interruption, to observe and time the rise of water in the well.

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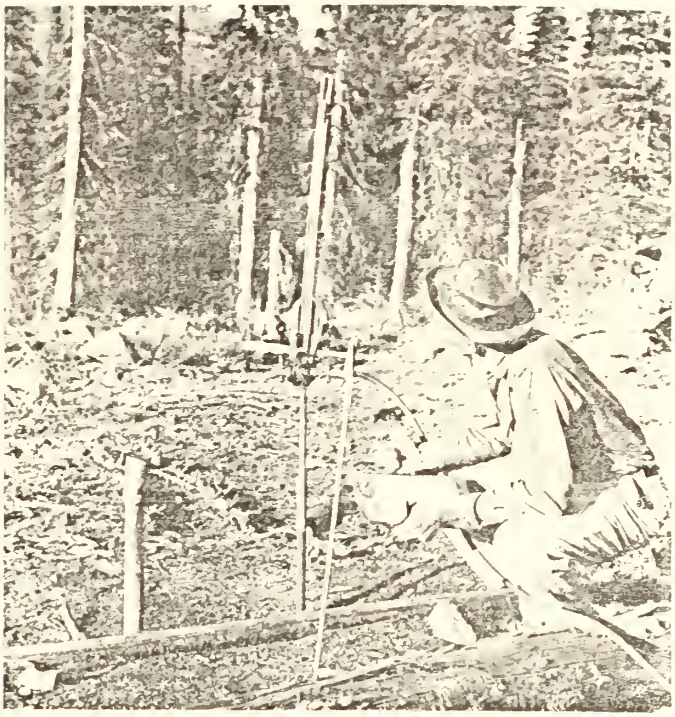

Figure 1.--Measuring hydraulic conductivity on the Elk Meadows research site, Idaho.

The pump-manometer consists of an air-liquid manometer built into the suction tube of a pump. After the pump has drained the well, a valve can disconnect the pump and the manometer can immediately function to measure rate of rise in the well. The level of the rising water is indicated by an extension of the manometer fastened to a scale. Burroughs (1967) and Richardson (1966) have reported that the pump-manometer has been used successfully in wells drilled in rocky soils and cased with 3/4-inch pipe on a study site in Idaho (fig. 1).

MANOMETER CONSTRUCTION SPECIFICATIONS

Major components of the pump-manometer are indicated by numbers in figure 2. The manometer scale (2a)[2] is 3/4- by 3/4- by 1/8-inch aluminum angle. The support is an 1/8-inch aluminum channel that clamps to a backplate (2b) of 1/4-inch aluminum slotted to allow vertical adjustment of the manometer scale (fig. 3).

The body of the manometer is composed of a copper 3/4-inch tee (6c) that has a slot (1 inch long and 3/8 inch wide) cut in the top. A 1/2-inch steel suction tube ([illegible] is fitted into the bottom of the copper tee by means of an adapter machined for snug fit and these pieces are silver soldered. A 5/16-inch hole is drilled 1 inch above the bottom of the suction tube to form the manometer inlet (10). A piece of 1/4-inch copper tubing, 1 foot longer than the suction tube, is inserted in the bottom of the suction tube and out the slot in the top of the tee. The lower end of the copper tube is bent in such a way that (as it is pulled into the suction tube) it will press against the sides of the tube and will drop into the 5/16-inch hole (fig. 4). The copper tube is pulled into the 5/16-inch hole, silver soldered, and filed flush with the outside of the suction tube. Two pieces of 1/4-inch copper tubing are cut 1 foot longer than the suction tube and one end of each piece is bent as sharply as possible without causing the tubing to collapse. The two pieces are laid side by side with the bends overlapping. A cut is made through both pieces so that when the cut ends are joined, there will be approximately 1/8 inch between the two lengths of copper tubing (fig. 4). The joint is silver soldered and slipped into the bottom of the suction tube. Then, the upper ends of the copper tubing are pulled through the slot in the top of the tee.

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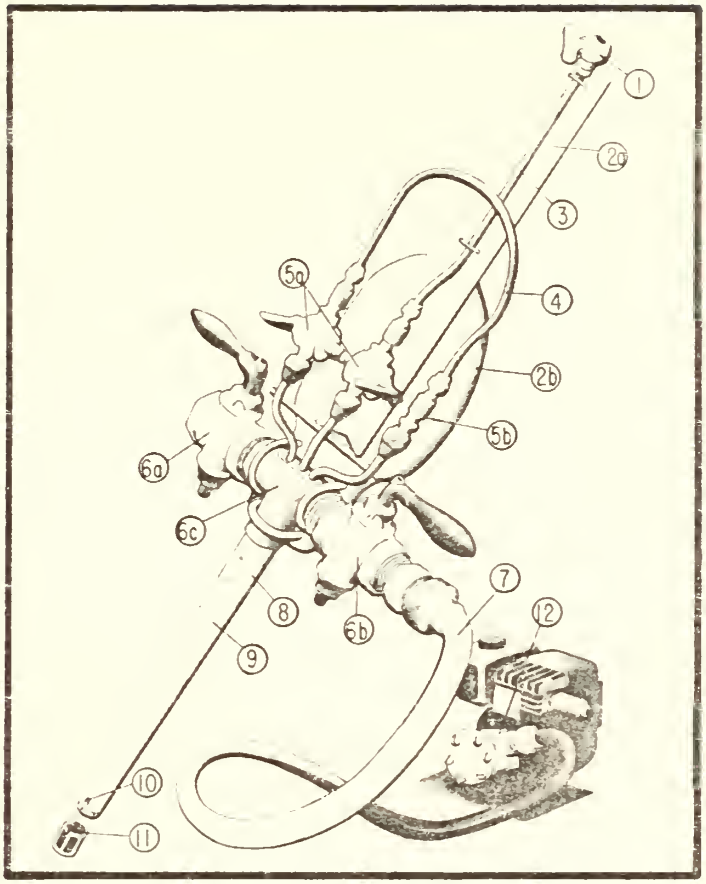
[2] Numbers in parentheses refer to appropriate figure.



<table>
<tr><th colspan="4">PARTS LIST</th></tr>
<tr><th>KEY</th><th>DESCRIPTION</th><th>KEY</th><th>DESCRIPTION</th></tr>
<tr><td>1</td><td>Manometer vent valve</td><td>6b</td><td>Pump valve</td></tr>
<tr><td>2a</td><td>Manometer scale</td><td>6c</td><td>Copper tee 3/4X3/4X3/4</td></tr>
<tr><td>2b</td><td>Manometer back plate</td><td>7</td><td>Pump hose 3/4"</td></tr>
<tr><td>3</td><td>Plastic manometer tube</td><td>8</td><td>Suction tube</td></tr>
<tr><td>4</td><td>Plastic loop</td><td>9</td><td>Suction tube scale</td></tr>
<tr><td>5a</td><td>Manometer valves</td><td>10</td><td>Manometer inlet</td></tr>
<tr><td>5b</td><td>Union connector</td><td>11</td><td>Strainer</td></tr>
<tr><td>6a</td><td>Bleed valve</td><td>12</td><td>Self-priming pump unit</td></tr>
</table>

Figure 2.--Manometer parts.

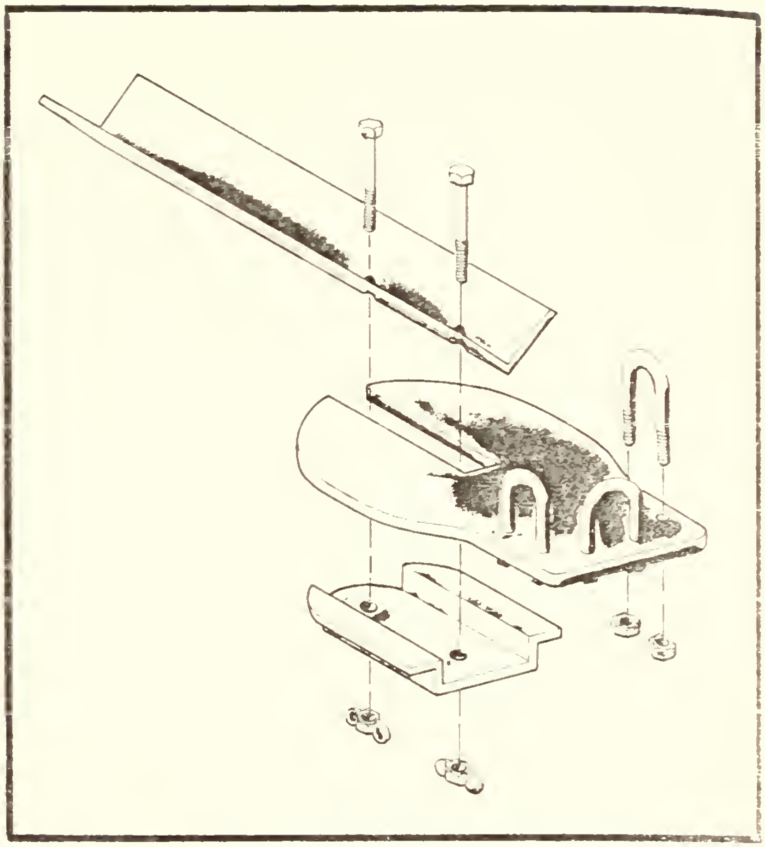


Figure 3.--Manometer scale, backplate, and support.

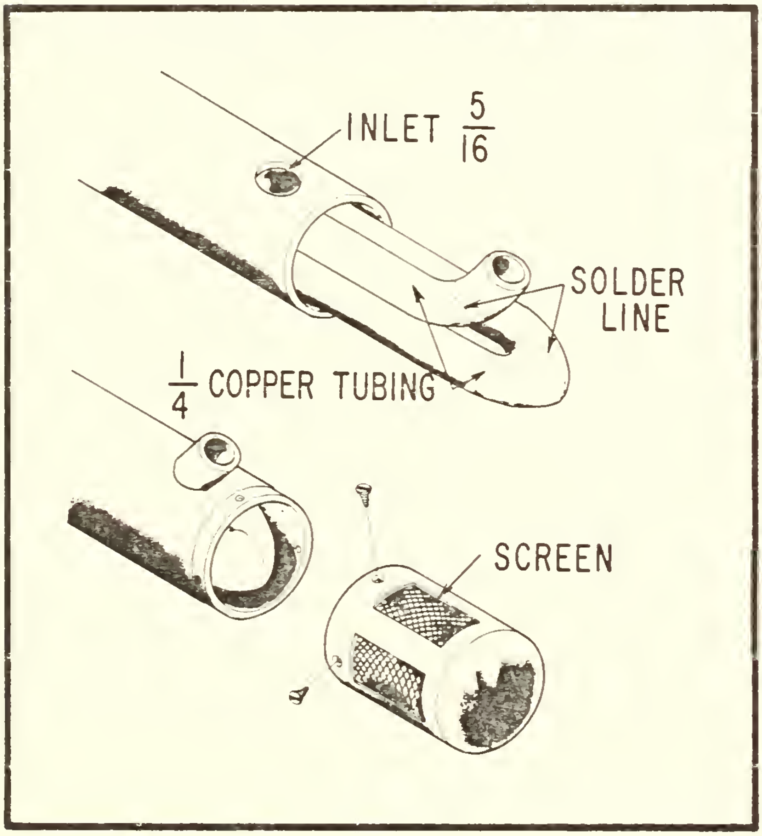


Figure 4.--Lower suction tube assembly details.

The copper tube from the manometer inlet is positioned on the left side of the slot and cut off about 3-1/2 inches above the tee. A nut is placed on the tube and the tubing flared (fig. 2). One of the ends of the joined tubes is placed in the center of the slot and the tube cut off about 2 inches above the tee. A nut is placed over the end and the tubing flared for later attachment to the plastic manometer tube (3). The remaining copper tube is cut, a nut installed, and the tube flared to match the manometer inlet tube on the left side of the slot.

Two brass, 1/4-inch shutoff cock valves (5a) are installed on the manometer inlet tube and the center tube. A piece of 1/8-inch brass welding rod is silver soldered to all three copper tubes to act as a brace. The slot in the tee, from which the three tubes exit, is closed with silver solder. The aluminum backplate is fastened to the copper tee with U-bolts (fig. 3).

A copper 3/4- by 3/4-inch adapter is inserted in each end of the copper tee and silver soldered in place. A brass, 3/4-inch stop-and-drain cock (6a and 6b) is threaded onto each adapter. A garden hose adapter is screwed onto the pump valve (6b). A full union (5b) is fastened on the right-hand tube. The upper end of each fitting is equipped with a compression fitting for plastic tubing. A piece of 1/4-inch plastic tubing (4), about 14 inches long, connects the manometer inlet tube with the right-hand tube. A piece of 1/4-inch plastic tubing (3), 2 inches longer than the manometer scale, is connected to the center tube. A small, brass manometer vent valve (1) is installed on the upper end of the plastic manometer. The manometer scale (2a) and its support are bolted to the backplate (2b), and the plastic manometer (3) fastened to the scale (2a) with metal clips.

PUMP SPECIFICATIONS

A Jabsco bronze self-priming gasoline motor pump unit[3] is attached to the instrument by a length of 3/4-inch garden hose (fig. 5). This pump unit weighs 32 pounds and is powered by a Briggs and Stratton 3-1/2 horsepower, 4-cycle, 2,000-rpm, "shock-free" gasoline engine with a windup starter and carrying handle. A parts breakdown of the pump is shown in figure 6.

The impeller (4) is made of a heat-resistant Neoprene compound that has excellent sealing qualities. The wear plate (6) may have to be replaced periodically if water contains sand. The pump body (9) is internally fitted for 1-inch diameter pipe. This pump is capable of pumping 35 gallons per minute to a 10-foot head or 24 gallons per minute to an 80-foot head.

The strainer (11) used in the pump-manometer is made from 60-mesh brass screen (fig. 2). It is cylinder-shaped, 1 inch long, and fitted on the lower part of the suction tube where it is held in place by screws.

CALIBRATION

The manometer fluid is ethyl alcohol. Enough dye is added to provide a good color contrast with the manometer scale. The manometer is primed by injecting the alcohol-dye mixture into the upper end of the plastic manometer with a syringe. The system is primed when the fluid level rises to the zero level on the manometer scale. It is important to keep the manometer vent valve and the two manometer valves closed when the instrument is idle to prevent evaporation or spillage.

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[3] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

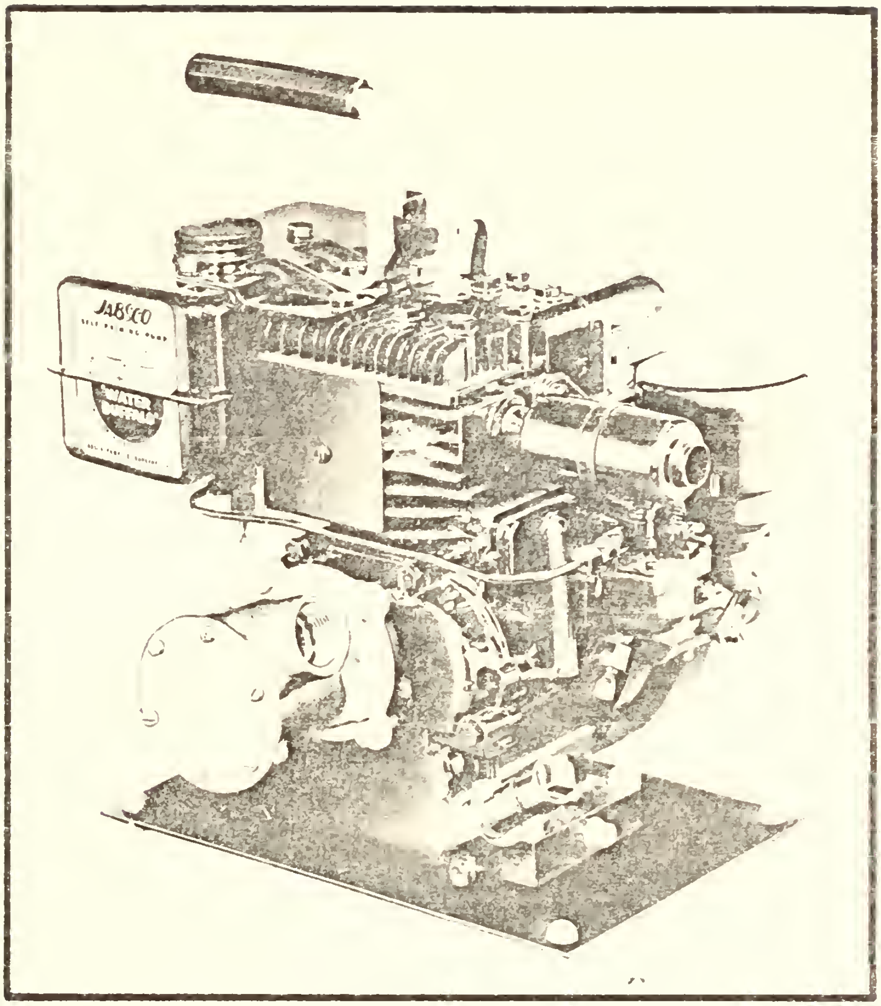
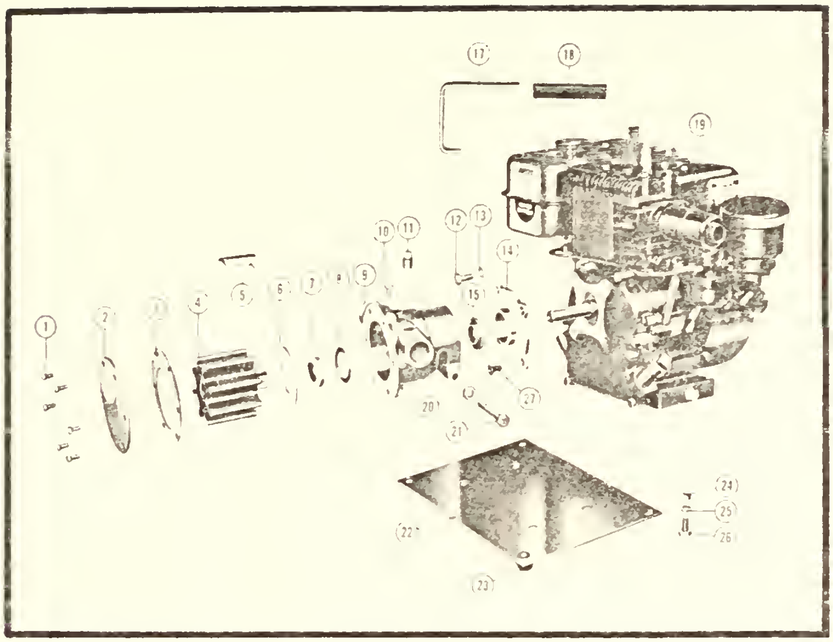


Figure 5.--Self-priming gasoline motor pump unit.

It is necessary to calibrate the instrument so that a unit length of rise in wells can be accurately measured by the air-liquid manometer. There are two reasons for calibrating the manometer: first, compression of the air by the rising water results in a shortened manometer scale; and second, the thermal characteristics of the manometer fluid are different from water. Consequently, the calibration process should be carried out in water of the same temperature as that of the ground water. The calibration process integrates the compression effect of the trapped air and the thermal characteristics of the manometer fluid at a given temperature. Water used to calibrate this manometer had a temperature of 40° to 45° F.

The manometer is calibrated in a tank or tube, at least as deep as the wells that are to be measured. The blank scale is inserted behind the manometer tube and the water level in the tank is raised until the manometer inlet is covered. The zero point is carefully scribed on the scale opposite the meniscus of the fluid. The water level is raised 1 inch and a new mark is scribed on the scale. Alternate scales may be made by transforming the original scale into tenths of feet or centimeters. The suction tube is scored at 1-inch intervals beginning at the upper side of the inlet hole (part [illegible], fig. 2). The appropriate number is stamped on each scored ring so the distance above the inlet tube can be easily read.



PARTS LIST					
KEY	DESCRIPTION	QTY REQ	KEY	DESCRIPTION	QTY REQ
1	Screws, end cover	6	14	Adaptor	1
2	End cover	1	15	Slinger	1
3	Gasket	1	17	Handle	1
4	Impeller assembly	1	18	Handle grip	1
5	Cam	1	19	Engine	1
6	Wearplate	1	20	Nut	1
7	Seal shaft	1	21	Bolt	1
8	O-ring	1	22	Base	1
9	Body	1	23	Rubber bumper	4
10	Screw, cam	1	24	Nut	4
11	Plug	1	25	Washer	4
12	Bolt	2	26	Bolt	4
13	Washer	2	27	Flat head screw	2

Figure 6.--Breakdown of self-priming pump parts.

The theoretical depth from which water can be pumped depends on a number of factors, such as barometric pressure, water temperature, type of pump, etc. For practical application, the best method that can be used to determine the maximum depth of a well with this manometer is described below. Place a 25-foot suction hose on the type of pump to be used. Insert the suction hose in a well of desired depth. Start pump and remove water until maximum depth is reached (at sea level this is about 20 feet). The suction tube on the manometer cannot exceed this length, but the manometer handles best at a depth of less than 12 feet.

OPERATION

Certain dimensions of the well must be determined before field measurements of hydraulic conductivity can begin. These dimensions define the initial depth of the well and the initial (or static) depth of water in the well. Refer to figure 7 which illustrates the following dimensions:

D - Depth of the well below the datum, which is the soil surface for the auger-hole method and the top of the well casing for the piezometer method;

E - Depth of the static water level below the datum;

d - Depth of the water in the well for both the auger-hole method and piezometer method, d = D - E;

L - Depth from the datum to the water surface in the well;

h - Average depth of water from the bottom of the well;

R - Radius of the well; and

s - Distance from the bottom of the well to the restricting layer.

E is determined by slowly lowering the suction tube into the well until the fluid in the manometer begins to move from its zero position; the scale on the outside of the suction tube at the datum level indicates the depth to water below the datum. D is determined by lowering the suction tube into the well until it rests on the bottom, and by reading the scale on the outside of the suction tube at the datum level and adding the 2 inches that the suction tube screen extends below the manometer inlet. The instrument is allowed to remain immersed for 2 minutes to allow the fluid in the suction tube portion of the manometer to come to thermal equilibrium with the well water. At equilibrium conditions, the manometer fluid may have increased or decreased its volume depending on its initial temperature. The instrument, which is withdrawn from the well until the manometer inlet is above the water, then is lowered until the fluid begins to move from its zero position. Note that the manometer screen extends 2 inches below the manometer inlet; therefore, the manometer scale is adjusted vertically until the 2-inch mark on the scale corresponds to the fluid level visible in the plastic manometer.

With the preliminary measurements completed, the instrument can be lowered to the bottom of the well and the pump can be started. The bleed valve (part 6a, fig. 2) should be closed and the pump valve (6b) opened. The manometer will indicate the falling water level. When the well is empty, the air moving past the manometer inlet (10) and up the suction tube (8) will cause the manometer to indicate a negative water level. At this point, the pump valve (6b) is closed and the bleed valve (6a) is opened. Laboratory tests show that only 30 ml. of water is retained in the suction tube after the well is pumped dry. When the pump valve is closed, this water drops back but causes only a negligible amount of water rise in the well. Ground water will immediately begin to rise in the well and the fluid in the manometer tube will begin to move as soon as water covers the manometer inlet.

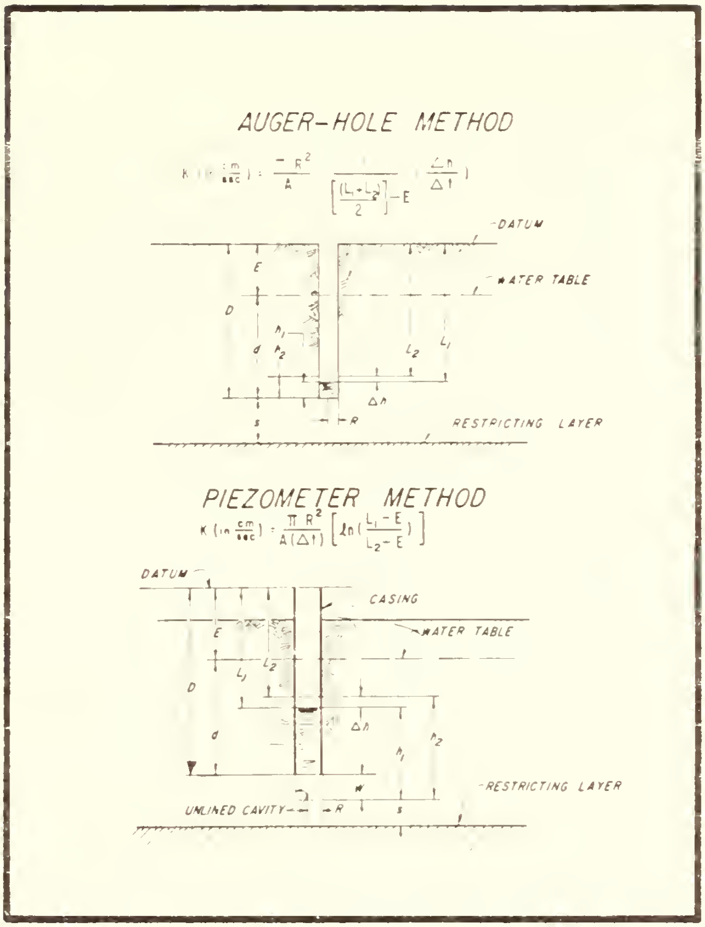

AUGER-HOLE METHOD
$K\ (\text{in}\ \frac{cm}{sec}) = \frac{\pi R^2}{A} \frac{1}{\left[\frac{(L_1+L_2)}{2}\right]-E} (\frac{\Delta h}{\Delta t})$
DATUM
WATER TABLE
E
D
h_1
d
h_2
L_2
L_1
Δh
s
R
RESTRICTING LAYER
PIEZOMETER METHOD
$K\ (\text{in}\ \frac{cm}{sec}) = \frac{\pi R^2}{A(\Delta t)} \left[\ln(\frac{L_1-E}{L_2-E})\right]$
DATUM
CASING
WATER TABLE
E
L_2
L_1
D
Δh
d
h_2
h_1
W
RESTRICTING LAYER
UNLINED CAVITY
R
s

Figure 7.--Dimensions used in both the auger-hole and piezometer methods to determine hydraulic conductivity in the field. (Adapted from Boersma 1965).

In sandy and gravelly soils, the rise of water in the first inch is usually so rapid that the operator may not be able to begin timing until the manometer fluid reaches the first inch above zero. The operator should be poised to time the rise of the fluid between convenient intervals on the manometer scale. A skilled operator can time alternate 1-inch intervals on the manometer scale. For accurate calculation of hydraulic conductivity with the auger-hole method, all measurements should be completed before the water in the well has reached a depth of 0.2d. For the piezometer method, measurements may continue until the water in the well has risen to within 20 cm. of its static level (Boersma 1965). Measurements should not be repeated until the water in the well has returned to its original static level. During operation, it is important to turn the instrument so that the plastic manometer tube is not exposed to direct sunlight for extended periods of time; error can be introduced by heating and expansion of the manometer fluid.

CALCULATIONS

The equations for calculating the hydraulic conductivity, K in cm./sec., are given in figure 7. "A" is a geometric factor in units of length, which relates the flow rate of water into the well to d, R, and s. "A" can be determined for both the auger-hole and piezometer methods by means of the procedure outlined in Boersma (1965). Because the pump-manometer measures h instead of L, the computation of the hydraulic conductivity in terms of h will be given for the two methods.

For the auger-hole method the term

$$\left[\frac{(L_1 + L_2)}{2}\right] - E$$

is equivalent to

$$\frac{(L_1 - E) + (L_2 - E)}{2} \qquad \text{Eq. 1.}$$

Since

$L_1 - E = d - h_1$

and

$L_2 - E = d - h_2$,

Equation 1 may be rewritten as

$$\frac{(d - h_1) + (d - h_2)}{2},$$

which can be reduced to

$$d - \left[\frac{(h_1 + h_2)}{2}\right].$$

The computational formula for K can be converted to:

$$K = \frac{\pi R^2}{A} \quad \frac{1}{d - \left[\frac{(h_1 + h_2)}{2}\right]} \quad \frac{\Delta h}{\Delta t}.$$

For the piezometer method, the quantity

$L_1 - E$

is equivalent to

$d - h_1$.

The equation for hydraulic conductivity for the piezometer method is

$$K = \frac{\pi R^2}{A(\Delta t)} \quad \ln \left[\frac{d - h_1}{d - h_2}\right].$$

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APPENDIX

Suggested computation sheets are given below.

Height of water in well (cm)	Rise increment (cm)	Time increment (sec)	Ratio $\frac{\Delta h}{\Delta t}$	$\frac{h_1 + h_2}{2}$	$d - \left[\frac{h_1 + h_2}{2}\right]$	$\frac{1}{d - \left[\frac{h_1 + h_2}{2}\right]}$	$\frac{\pi R^2}{A}$	$K \frac{cm}{sec} = \frac{\pi R^2}{A} \frac{1}{d - \left[\frac{h_1 + h_2}{2}\right]} \frac{\Delta h}{\Delta t}$
1	2	3	4	5	6	7	8	9
h_1 =								
h_2 =								

*Figure 8.--Sheet for hydraulic conductivity by the auger-hole method**

Height of water in well (cm)	$d - h$ (cm)	$\frac{d - h_1}{d - h_2}$	$\ln\left[\frac{d - h_1}{d - h_2}\right]$	Time increment (sec)	$\frac{\pi R^2}{A}$	$K \frac{cm}{sec} = \frac{\pi R^2}{A(\Delta t)} \ln\left[\frac{d - h_1}{d - h_2}\right]$
1	2	3	4	5	6	7
h_1 =	$d - h_1$ =					
h_2 =	$d - h_2$ =		Δt =			

*Figure 9.--Sheet for hydraulic conductivity by the piezometer method**

* Adapted from Boersma 1965.